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M shell X-ray production cross sections in Au, Pb, Th and U by Sn *K* X-rays

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Abstract : The cross sections for the production of *M* shell X-rays in thick targets of Au, Pb, Th and U by *K* X-rays of Sn have been measured. As the incident *K* X-ray energies are above the Li edge energies of the elements under reference, the *M* X-rays are produced not only due to direct interaction of incident photons with *M* shell electrons but also due to the shift of the *L* shell vacancies to the *M* shell. The experiment has been performed using a double reflection geometrical setup with a 1 Curie Am-241 gamma ray source and a Si (Li) X-ray spectrometer. The measured values have been compared with those calculated using known values of *L* shell photoionization cross sections and fluorescence yields etc., wherever possible It is seen that the shift of *L* shell vacancies to *M* shell contributes nearly 85% of the total *M* shell X-rays produced in these cases.

Keywords : *M* shell X-rays, production cross section

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1. Introduction

Some measurements of the cross sections for the production of *M* X-rays due to direct photoionization of *M* shell electrons in elements Au, Pb, Th and U at energies ranging from 6–11 keV, have been reported recently by the authors [1]. In situations, where the energy of the incident photon is higher than the *K* edge energy of the element, *M* shell X-rays in the element will also be produced through the decay of *K* and *L* subshell vacancies to *M* shell in addition to direct photoionization of *M* shell electrons. The experimental as well as theoretical data on *M* X-ray production by the decay of *K* and *L* subshell vacancies to *M* shell are scarce. In order to provide experimental data on the production of *M* X-rays due to the decay of *L* subshell vacancies to *M* shell through radiative and non-radiative transitions and test the theoretical calculations of the probability of transfer of *L* subshell vacancies to *M* shell, we have extended our earlier measurements to photon energy which is below the *K* edge energies and above the *L* edge energies of the elements, so that *K* shell electrons are not ionized but *L* and higher shell electrons are ionized. The method of measurement and results are reported in this paper.

2. Method, measurements and results

59.57 keV gamma rays from 1 Curie 241-Am source were collimated to fall on a self supporting primary target of Sn in form of circular disc of dia 4 cm and radiation emitted from this were again collimated, in turn, on secondary targets of Au, Pb, Th and U of dia 4 cm each. The *M* shell fluorescent X-rays emitted from the secondary targets as a result of interaction of radiation emitted from primary target with secondary target elements were analysed using Si (Li) X-ray detector with resolution nearly 170 eV at 5.9 keV. The experiment was performed in a double reflection geometrical setup described in detail earlier [2]. Typical spectra of radiation emitted from Th secondary target when it is bombarded with : (a) radiation from Sn primary target and (b) Equivalent Al primary targets are shown in Figure 1(a) and the subtracted spectrum (a) – (b) is shown in Figure 1(b). As explained in

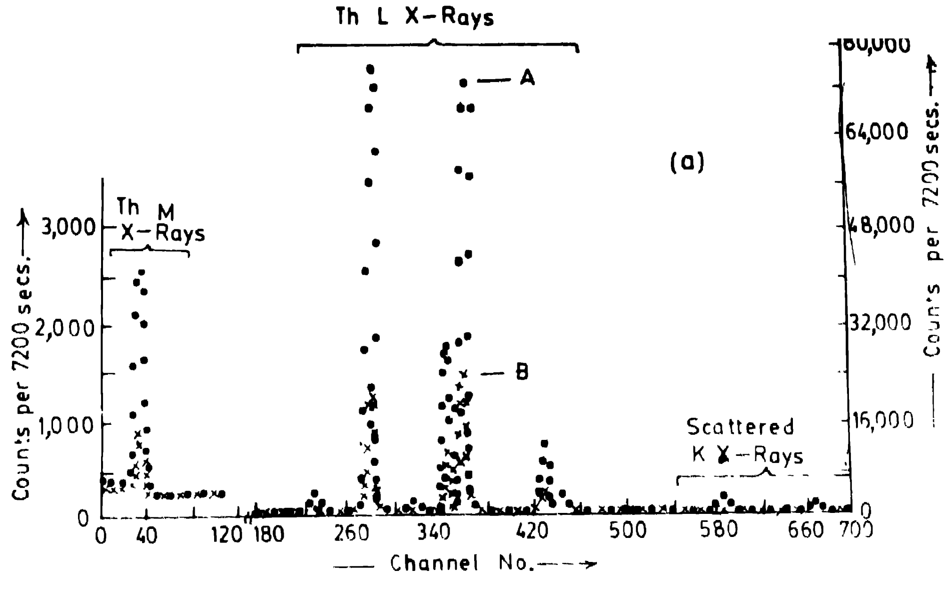

Figure 1(a). Spectrum of Th target recorded with the Si(Li) X-ray detector when irradiated with A – Sn primary target, B – Eq Al primary target.

detail earlier [2], the spectrum of radiation in Figure 1(b) is due to the radiation emitted from the secondary target as a result of interaction of *K* X-rays of the primary target with *L*, *M* and higher shell electrons of the secondary target. In this spectrum, contrary to the earlier case, the secondary target *L* shell X-rays are also seen in addition to secondary target *M* X-rays and scattered primary target *K* X-rays. This is because the *K* X-ray energy of the primary target element is above the Li subshell threshold of the secondary target element. The *M* shell X-ray production cross sections were determined by measuring the absolute intensity of *M* shell X-rays when the secondary targets are bombarded with known flux of primary target *K* X-rays. The other details of the experiment were similar to the one as reported in detail earlier [2].

The measured values of the M shell X-ray production cross sections are listed in Table 1. Since no other experimental measurement of the cross section at the energies under

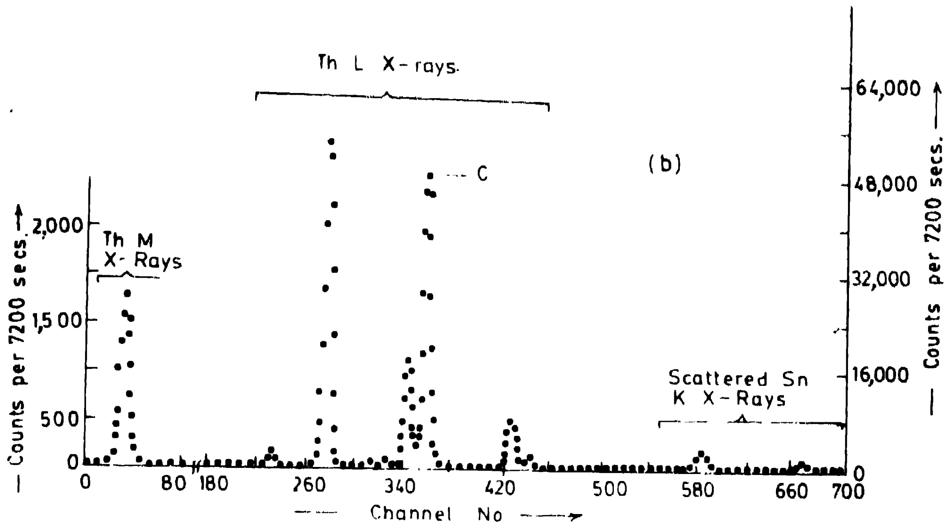

Figure 1(b). Spectrum of Th target recorded with the Si(Li) X-ray detector when irradiated with C = A - B

reference are available in literature, the results have been compared with theoretically calculated values only, wherever possible. The theoretical calculation were made using the following relation :

$$\sigma_M^x = \left(\sigma_M + \sum_{i=1}^{3} \sigma_{Li} \cdot n_{LiM}\right) \cdot \overline{W}_M$$

where

σ_M^x	is the total M shell X-ray production cross section
σ_M	is the total M shell photoionization cross section
σ_{Li}	is the Li subshell photoionization cross section (i = 1, 2, 3)
n_{Li}	is the probability that a vacancy in the Li subshell will shift to M shell
$\overline{W}_M$	is the average M shell fluorescence yield

For the purpose of calculations, the values of σ_M have been taken from the tables of Scofield [3]. For values of n_{LiM} and $\overline{W}_M$ the calculated values of McGurie [4] and semi-empirically fitted values of Hubbell [5] have been used respectively. The theoretical calculations could be made for Au and Th only as in the other two cases, the values of n_{Li} are not available.

The theoretical calculations of the cross sections using subshell photoinonization cross sections and fluorescence yields, Coster-Kronig and super Coster-Kronig transition probabilities, L_i subshell to M_j subshell vacancy transfer probabilities etc. could not be made, as done in the earlier case [2] due to non-availability of relevant data sets of the parameters for elements under reference. The calculated values are found to be somewhat lower than the experimental values. However, more theoretical and experimental data on various M shell parameters are needed before a meaningful comparison between theory and experiment become possible. The component of the percentage contribution due to shift of L shell vacancies to M shell to the total M shell X-ray production cross sections were estimated using the relation :

$$\frac{\sigma_M^x\ (\text{measured}) - \sigma^M}{\sigma_M^x\ (\text{measured})} \cdot 100$$

The results are also shown in Table 1. It is seen that nearly 85% of the total M X-rays produced in the elements under reference are due to the shift of L subshell vacancies to M shell and the contribution due to direct photoionization is nearly 15% only.

Acknowledgment

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